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R & D work in composites at the Fibre-Reinforced Plastics Research Centre

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Abstract. This paper briefly presents some of the R & D activities taken up by the Fibre-Reinforced Plastics (FRP) Research Centre, Indian Institute of Technology, Madras, in the last seven years. The studies covered in this paper include the analysis of heat shield, development of vibration mounting for rocket motor casings, design and development of metal-lined pressure bottles, study of the effect of nuclear radiation on filament wound shells, design and development of high voltage disc insulators, study of underwater-acoustic characteristics of FRP and development of some of the processing techniques. The paper also lists a number of products developed by the Centre for meeting the immediate needs of society. Finally, the on-going academic and sponsored research programmes are briefly outlined.

Keywords. Composites; fibre-reinforced plastics.

1. Introduction

The Fibre-Reinforced Plastics (FRP) Research Centre was set up by the Indian Institute of Technology (IIT), Madras, in 1974, with a view to take up research, teaching, technology development and consultancy in the area of composites technology. It is one of the four interdisciplinary research centres of the Institute and has established over the last 13 years an identity of its own, and has good rapport with industries and other institutions in the country.

The research and development activities of the Centre can be broadly grouped into the following:

(i) academic research aimed at generating scientific knowledge;

(ii) R & D studies to stimulate the use of composites for certain high technology developments in the country;

(iii) The development of certain products that directly benefit society.

Six papers (Babu 1988; Kari Thangaratnam *et al* 1988; Malhotra *et al* 1988; Nair & Premachandran 1988; Rajanna *et al* 1988; Santhanakrishnan & Krishnamoorthy 1988) being presented at the International Conference on Composite Materials and Structures (ICCMS-88) at IIT, Madras, reflect the nature of the academic research activities at the Centre. They include studies in the area of micromechanics, rheology of composites, buckling, flutter and dynamic analyses of laminated composites using finite element methods, software development for analyses of composite structures, and machining and friction characteristics of fibrous composites.

The development and use of technology requires certain studies that are of immediate interest to the nation. Although a developing country like India with R & D activities in several high technology fields needs the use of composite materials, it is also necessary to study and find out how best composite materials can be put to use for general social development. This paper briefly summarizes some of the R & D studies taken up by the FRP Centre towards these goals.

2. Background

Industrial activity in the area of composite materials started in the country in 1962 when Fibreglass Pilkington Ltd. was established for producing glass fibre in India. Research activities in the field of composites also started in the early 60s, but the activities during the 60s and early 70s were mainly confined to the theoretical studies on composite structures, treating them as anisotropic laminates or sandwich materials. The National Aeronautical Laboratory (NAL), Bangalore, and the FRP division of the Vikram Sarabhai Space Centre, Trivandrum, were the two organizations engaged in the development of products and processing technology in composites during this early period. In the early 1970s, the National Committee for Science and Technology of the Government of India emphasised that the development of composite materials must be taken up as a thrust area and importance must be given both for research and for manpower development in this field. In order to effectively take part in this national effort, IIT, Madras, set up the FRP Research Centre with the following objectives:

—to work for the advancement of composites technology and its applications;
—to undertake teaching, research, manpower training and other technical activities in order to meet the requirements of the FRP and allied industries;
—to provide advice, consultancy and technical leadership to the FRP and other composite materials industry in the country.

While theoretical studies have been given due importance, equal emphasis has been placed on experimental investigations, product development, design consultancy, and testing and quality control guidance to the industry so that IIT, Madras, can effectively contribute to the development of composites technology in the country. The Centre has now 5 faculty members and 9 supporting staff and is equipped with a composite materials laboratory, composite structures laboratory, FRP workshop and machine shop. A composites facility funded by the Department of Science & Technology, Government of India, New Delhi, exists at the Centre for providing testing and quality control services to the industries concerned.

3. Analysis of re-entry vehicles

Re-entry vehicles are used in space flights and missiles technology for bringing back a payload from space into the earth's atmosphere. The payload may include astronauts, sophisticated instruments, technical data collected by the satellite during its space flight or some warhead in the case of missiles. The vehicle that enters the earth's atmosphere at an altitude of about 80 km above sea level at velocities of the order of Mach number 11 at re-entry, experiences aerodynamic heating raising the temperature around the vehicle to about 2600 K. A heat shield made of carbon-phenolic or carbon-carbon is used for dissipating the heat by the ablation of the material and for protecting the payload within allowable limits of the inside temperature (300 K). A study was conducted at the Centre by Mohideen (1985) for developing the analysis and design capability for predicting the trajectory, and determination of skin temperature on the heat shield, temperature distribution through the thickness of the heat shield, and the stresses developed in the heat shield due to the aerodynamic pressure loading as well as due to the thermal gradient through the thickness. Figure 1a shows the shape and dimension of a heat shield chosen for the analysis. Stress analysis techniques have been developed using finite element methods for the following cases:

(i) Stress analysis under the axisymmetric loading of aerodynamic pressure, deceleration and thermal stresses. SAPIV four-node isoparametric 2D and beam elements have been used for the analysis. Figures 1b and c show axial and circumferential stresses plotted along the length due to the combined effect of pressure, inertial and thermal loadings.

(ii) Stress analysis under non-axisymmetric loading corresponding to the non-zero angle of attack. Shell elements have been used for the finite element analysis.

(iii) Stress analyses of the regions of high stresses using 3D elements.

(iv) Buckling analyses of the shells under external pressure and thermal loading using semi-loof shell elements specially developed for composite materials.

(v) Frequency and mode shape analysis of the shell by the finite element method.

The FRP Research Centre has developed the competence and capability to carry out the design and analysis of heat shields of re-entry vehicles.

4. Vibration mountings of rocket-motor casing

The vibration characteristics of rocket-motor casings are studied by mounting them on conical shell supports of the type shown in figure 2. These shells must be light and stiff and the mounting under design must have natural frequencies in the range 800–1000 Hz so that they will not interfere with the vibration of the motor casings. Traditionally, magnesium alloys are made use of in making these mountings. Fabrication of magnesium alloy mounting shells involve costly machining operations and such mountings are currently being imported.

A study was taken up at the FRP Research Centre to see whether FRP could be used for fabricating such mountings. Carbon fibre-epoxy composites, although a potential materials system, were not considered due to their high cost. Instead, glass-epoxy shells with appropriate stiffening webs in-laid with aluminium were chosen for the study. The dimensions of the shell wall, stiffener size and thickness, dimensions of the aluminium inserts etc. were determined by a finite element analysis. The designed mounting was then fabricated by the hand lay-up method. Extensive evaluation of the mounting was carried out by the SHAR Centre of The Indian Space Research Organization and this study has shown that the natural frequency achieved was less than the value predicted by the finite element method of analysis. The shell was further

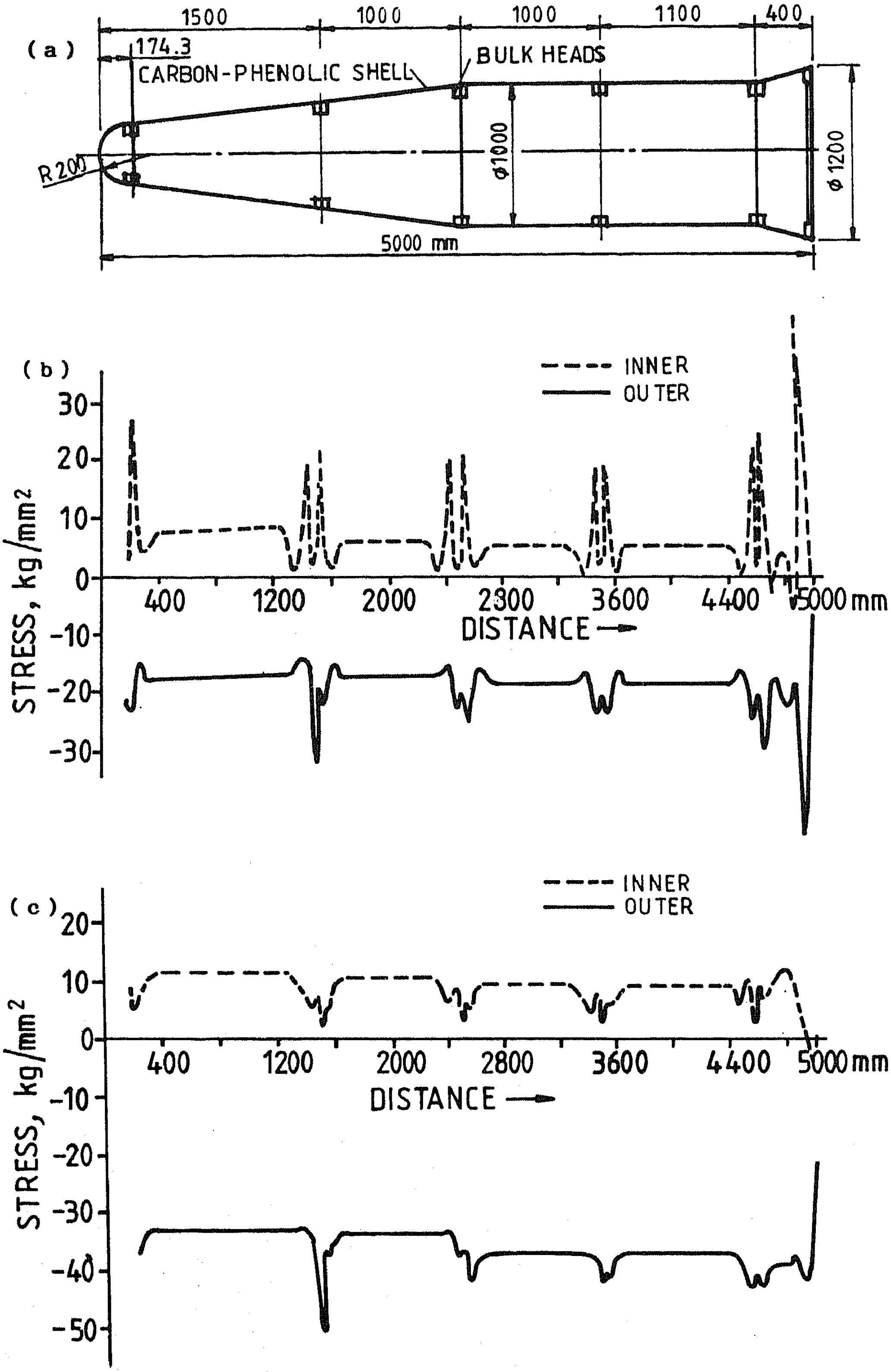

Figure 1. Stress distribution along the heat shield due to aerodynamic pressure; inertia and thermal loading. (**a**) Assumed shape of heat shield; (**b**) axial stress, and (**c**) circumferential stress.

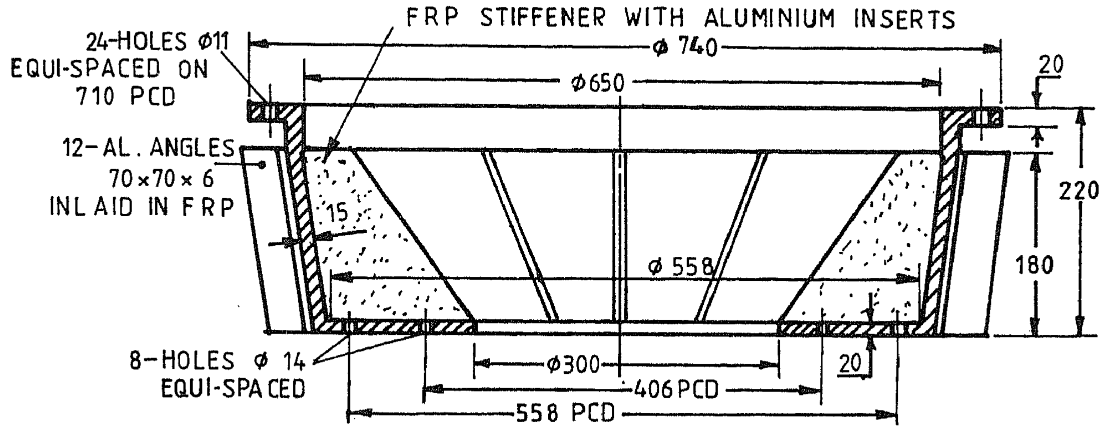

Figure 2. FRP vibration mounting.

stiffened by adding more stiffeners and glassfibre-reinforced plastic (GRP) layers. The improved vibration mounting is now undergoing trials at the SHAR Centre.

5. Metal-lined FRP pressure bottles

FRP pressure bottles find many applications in aerospace, hydrospace and military fields. They are used primarily for storing gases or liquified gases under high pressures. Applications include oxygen bottles, underwater buoys, missile casings, gas bottles for guidance of spacecraft etc. Pressure bottles made by the filament winding of glass, Kevlar or carbon fibre-reinforced epoxy composites develop matrix cracking at relatively low stress levels. Therefore, they are internally lined with metallic or elastomeric liners which provide impermeability even when the matrix has cracked and which allow the bottle to be used at higher pressure levels without weeping of the gases. Unlike elastomeric liners, metallic liners, if bonded properly, act as integral parts of the FRP shells. The metallic liner has the added advantage that it serves as a mandrel for polar winding of the pressure bottle.

Under a sponsored programme (Malhotra & Babu 1985), the FRP Research Centre took up a project for the design and fabrication of metal lined pressure bottles. The pressures to be withstood are upto 400 atmospheres. Glass epoxy was chosen as the material for fabrication of the shell because of its cost-effectiveness over carbon or Kevlar-epoxy systems.

5.1 *Development*

A study of the bonding of aluminium and stainless steel with various types of GRP by a series of lap shear tests (listed in table 1) has shown that aluminium and stainless steel with etching have good bonding with the glass-epoxy material. Etching has been done with a mixture of potassium dichromate, sulphuric acid and distilled water at 65–70° C. Aluminium is also compatible with filament wound glass-epoxy because its modulus is closer to that of the GRP than that of stainless steel. Because of this compatibility and because of its light weight and production advantage, aluminium was chosen as the liner material. Figure 3 shows the shape and dimensions of a typical aluminium liner with the filament wound FRP over the liner.

Table 1. Lap shear strength of metal-FRP bonded interface.

Metal layer used	FRP structure	Lap shear strength (N/mm^2)	
		Without etching of metal	With etching of metal
Aluminium	Glass CSM* and polyester	2·12	7·81
Aluminium	Glass WRM† and polyester	2·07	6·73
Aluminium	Glass WRM and epoxy	3·63	10·13
Stainless steel	Glassfibre CSM and polyester	2·28	4·86
Stainless steel	Glass WRM and polyester	4·74	16·09
Stainless steel	Glass WRM and epoxy	5·32	15·50

* Chopped-strand mat (source: Malhotra & Babu 1985);
† Woven roving-mat.

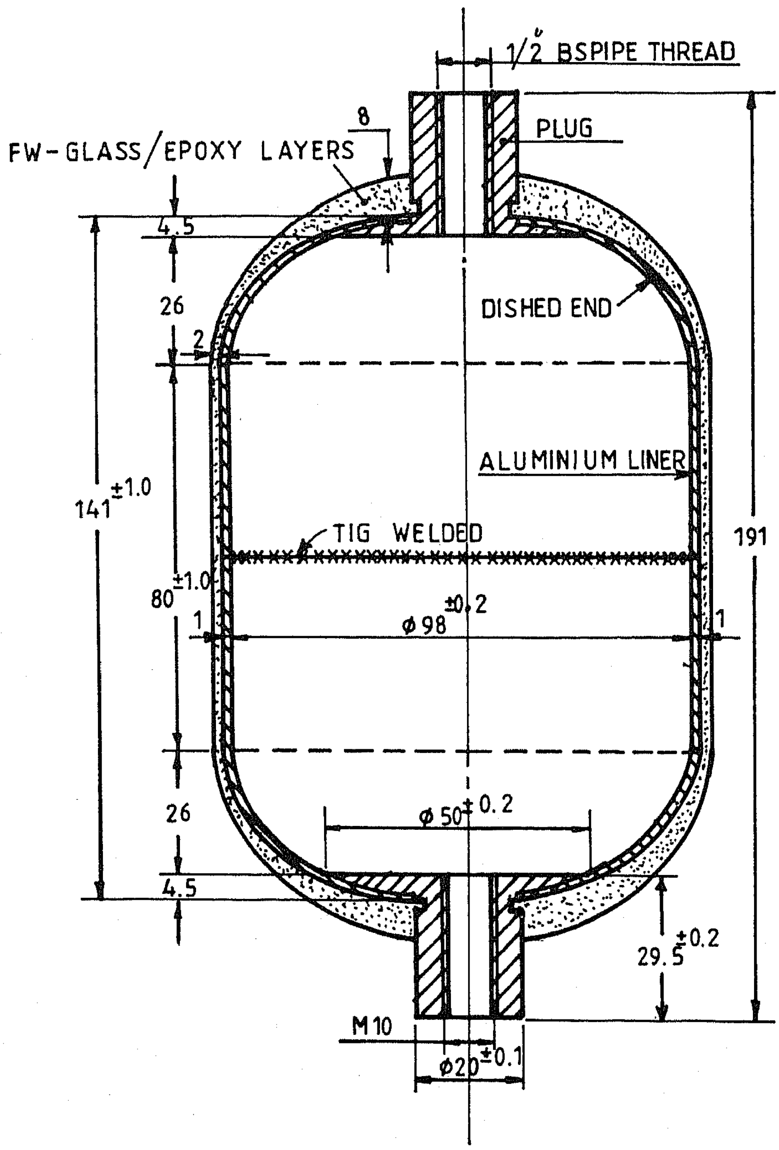

Figure 3 Glass-epoxy pressure bottles.

Table 2. Burst strength of metal-lined FRP pressure bottles.

Thickness of aluminium liner (mm)	FRP shell structure			Burst pressure (kg/cm^2)
	Roving tex	No. of double layers of polar winding	No. of layers of hoop winding	
1	Nil	Nil	Nil	6
Nil	1140	1	2	75
1	1140	1	2	165
1	1140	2	2	290
1	450	2	2	140
1	450	3	2	195
1	450	4	2	255

(Source: Malthotra & Babu 1985)

5.2 *Analysis*

A special purpose finite element analysis package using a four-node shell element with four degrees of freedom per node was developed for analysing the pressure bottle. The relative dimensions of the liner and FRP shell and the thickness of the FRP shell for strain control are decided based on this FEM analysis. An FEM can be used to predict the stresses and strains until the liner plastically yields or until the resin cracks, whichever is earlier.

5.3 *Fabrication and testing*

Pressure bottles were fabricated by using polar winding machine-designed and manufactured at the Centre. Glass-epoxy prepreg rovings were made in a laboratory model prepreg making set-up which is available at the Centre. The prepreg rovings were then wound on the liner, after which the bottles were cured in an oven. Pressure bottles with different layer thicknesses were made and tested in a burst pressure test set up. Table 2 gives the various ultimate pressures obtained in these cases. Design and fabrication of pressure bottles of up to 500 mm diameter that can withstand pressures up to 400 atmospheres is now possible.

6. Effect of nuclear radiation on filament wound FRP pipes

A project (Malhotra & Radhakrishnan 1984) was taken up to study the suitability of GRP pipes for use in nuclear radiation environment. Under this programme, glass-epoxy and glass-polyester-filament-wound pipes were fabricated and their properties determined before exposing them to nuclear radiation. The tubes were then subjected to five different total doses of nuclear radiation and then tested for their mechanical properties. Table 3 shows the percentage reduction in the axial tensile strength, axial compressive strength and hoop stiffness for various doses of nuclear radiation. The study has revealed that glass-polyester material is not suitable for long-term exposure to nuclear radiation whereas glass-epoxy pipes can be used for not-so-critical piping systems in nuclear plants. The very high reduction in hoop stiffness as compared to the

Table 3. Reduction in mechanical properties of filament wound FRP pipe due to nuclear radiation.

Total dose of radiation (mega rads)	Reduction in mechanical properties (%)		
	Axial tensile strength	Axial compressive strength	Diametral stiffness EI
Glassfibre–epoxy pipes			
244·12	6·60	4.25	20·00
298·91	6·38	6·25	24·00
655·58	6·86	7·13	22·39
973·55	7·24	7·82	23·4
1533·46	8·09	8·53	22·7
Glassfibre–polyester pipes			
244·12	9·30	4·96	7·09
298·91	9·63	11·78	12·75
973·55	12·79	13·93	14·73

(Source: Malhotra & Radhakrishnan 1984)

reduction in axial strength shows that nuclear radiation affects plastics more than it affects glass fibre.

7. Underwater acoustic performance of GRP

Underwater surveillance is generally based on sound signals because of the very low attenuation that sound waves suffer in the saline water of the oceans. In addition to substances like the piezo-electric materials used for electro-acoustic transduction, a few other materials, generally called passive materials, are being used as sound absorbers, sound reflectors or acoustic window materials. Glassfibre-reinforced plastics find application in sonar domes as acoustic window materials because of the combination of high mechanical properties, corrosion resistance and transparency to sonar signals offered by this material.

A study was taken up as a part of the academic programme (Narayana Das 1987) to understand the transmission and reflection characteristics of GRP and the effect of various materials parameters on these acoustic properties. GRP laminates of 0·5 m × 0·5 m were prepared using glass fibre in chopped-strand mat and woven roving-mat forms. Laminates with different layer thicknesses, fibre contents and void contents were prepared. Acoustic properties were measured in an acoustic tank facility. The study has yielded a number of behavioural characteristics of GRP. As an example, figure 4 shows the variation of maximum transmission loss with fibre content and void content for a woven roving-mat and chopped-strand mat laminate. A theory has been formulated for predicting the transmission characteristics of multi-layered FRP laminates using the experimentally obtained properties of the lamina.

8. FRP insulators for HV transmission lines

Ceramics are traditionally used for making disc/string insulators for the overhead

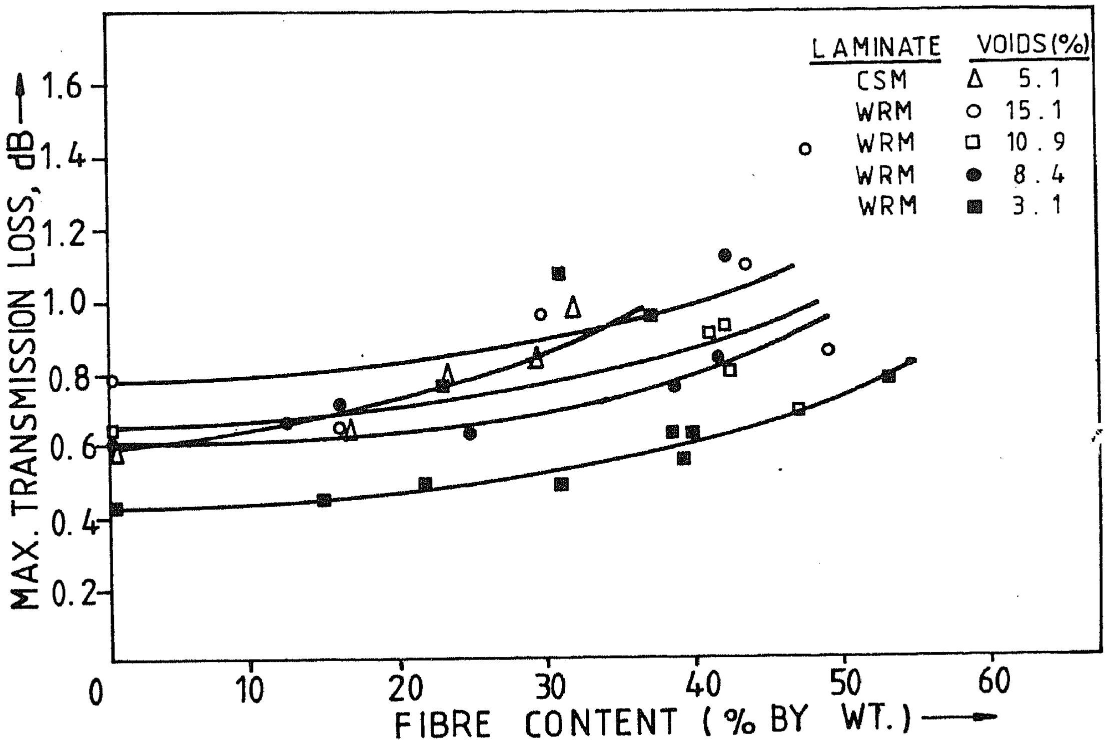

Figure 4 Effect of microstructure of FRP on the acoustic transmission loss.

transmission lines. They have excellent insulation properties and durability, but have poor impact strength and are heavy. The FRP Research Centre, under a master's degree programme for entrepreneurship, has developed a composite insulator system for high voltage (HV) transmission lines and this design can be easily extended to extra high voltage (EHV) lines. A multi-disc string insulator can be made either by assembling single-disc insulators as in the conventional system or by casting the discs over a central FRP rod. The weight of a five-disc insulator is less than 40% of the weight of an equivalent ceramic insulator. The discs have been designed to satisfy Indian Standard specifications. The product has been tested at the High Voltage Laboratory of IIT, Madras, and has been found to meet all the requirements as per Indian Standards. Figure 5 shows the typical section of a five-disc insulator cast on an FRP rod.

9. Development of process technology

Growth in the application of composite materials can be accelerated only if various processing technologies are developed indigeneously. In order to achieve this goal, several process development studies have been taken up at the Centre. (Premachandra 1984) has studied the rheological characteristics of injection moulding of reinforced thermoplastics using coaxially extruded glassfibre-reinforced thermoplastic pellets. The results of this study are quite useful for injection moulding of glass-filled materials in ram-type injection-moulding machines. A Rajanna (unpublished) has developed the reinforced reaction injection moulding (RRIM) of polymethyl methacrylate (PMMA). The fibre is packed in a closed mould and a reaction mixture of MMA is injected into the mould. The process yields a component in $2\frac{1}{2}$ hr as compared to the 6 hr required in conventional PMMA coating. Pradyut Datta (1984) has developed the process of coating

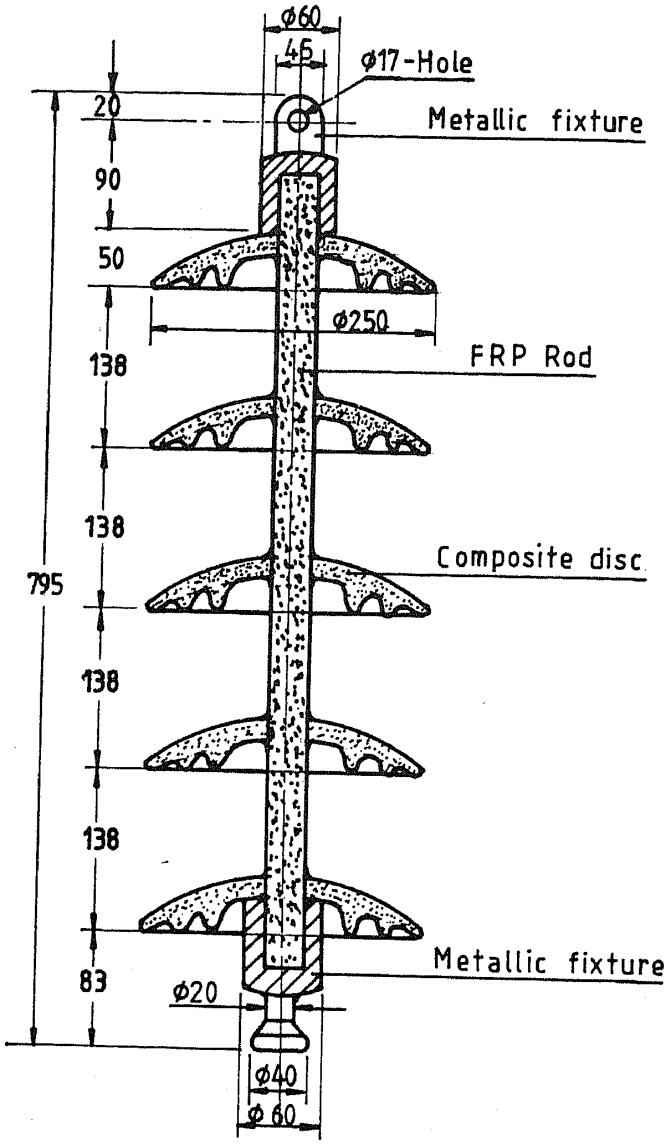

Figure 5. Composite multi-disc string insulators.

PVC, PTFE and polyurethane over glassfibre woven roving-mats and woven yarn cloth. These coated fabrics have high strength and impermeability making them suitable for inflated structures and biogas holders. Desai (1986) has developed a polymer-concrete-processing technique both for the surface finish grade and structural grade.

10. Product development

The adaptation of technology to meet immediate social needs cannot be ignored in any research programme taken up particularly by a developing country. FRP can be effectively utilized for a number of products that may directly benefit society or industrial production. A few products of this type as listed in table 4 have been developed by the FRP Research Centre.

India has an abundant supply of natural organic fibres like jute, coir, pineapple fibre etc. Among these fibres, jute has been found to have excellent mechanical properties. Under a sponsored programme, studies have been conducted to develop jute-polyester

Table 4. List of FRP products developed and fabricated at the Centre.

Product	Material used	Processing method
Prefabricated house ($20\,m^2$ area)	Jute-polyester	Hand lay-up
Prefabricated house ($20\,m^2$ area)	Jute-polyester	Filament winding
Window frames of express buses	Glass-polyester	Squeeze moulding
Doors of express buses	Glass-polyester	Hand lay-up
Tubes for H.V. Insulation	Glass-epoxy	Filament winding
Radio frequency former	Glass-epoxy	Filament winding and machining
Bio-gas holder	Glass-polyester	Hand lay-up
Microwave antenna (0·5, 1·2, 3·3 m dia.)	Glass-polyester	Hand lay-up
Wear-resistant composites	Silicon carbide-epoxy	Vibration compaction
Polymer concrete products	Glass-polyester	Vibration compaction and compression moulding

composites and to develop products like houses, silos and fishing boats. Jute-polyester laminates and sandwich sections have been developed and their load carrying capacity has been evaluated. The weathering of jute fibre and the consequent reduction in mechanical properties have been determined over a period of one year by exposing them to the natural environment, burying them under ground, and immersing them in fresh/sea water. Jute-polyester composites have shown excellent load-bearing characteristics but a gradual degradation of mechanical properties with time has also been observed.

11. On-going research programmes

A few research programmes initiated recently include theoretical studies, design and process technology development in different areas. Some of them are given below:
(i) delamination of laminated composites is being studied both theoretically using FEM techniques and experimentally using flaw detectors;
(ii) a computer-aided design system is being developed for the mould design and process simulation studies of the compression moulded SMC;
(iii) the code of practice-based design of FRP chemical equipment design is being formulated as an "Expert System" programme. The provisions of the British Standards code of practices BS4994 is coded as "IF-THEN" rules and chemical equipment design is being taken up as an Expert System for the formulation of the decision-making process;
(iv) the sol-gel process is a recently developed method for making high-strength ceramics, which have unique properties including superconductivity. Their production, involving the mixing of organic compounds with metals, could not be done satisfactorily before. In the sol-gel process, a metal can be 'hidden' in an organic compound and the mixture then baked at low temperature such that the organic compound evaporates resulting in a controlled mixture of atoms that high-temperature processing can not produce. A study has been initiated to develop silicon carbide reinforced ceramic systems using this process;
(v) development of RRIM of casting-grade nylon;
(vi) the thermoforming of carbon-fibre-reinforced thermoplastic prepregs;
(vii) development of glass filled nylon cycle parts, and

(viii) for high temperature applications involving thermal environment exceeding 150 °C, the development of matrix and adhesives, material characterization as well as process/fabrication technologies being important, a critical study of high temperature polymer matrix composites is being carried out.

12. Concluding remarks

In this paper, the various R & D activities of the FRP Research Centre (FRPRC) in the last seven years have been highlighted. These research studies cover a wide range of problems. It is worth pointing out that apart from theoretical/analytical research work, the FRPRC has been focussing equal attention on processing/fabrication methods and product development which in the field of composites are very important. This is because of the fact that in the case of composites, the material and the product being developed are totally interlinked, which is not the case when designing with conventional metallic materials. A designer cannot, therefore, design a product without due consideration being given to processing methods and the material system design. Thus product development involving composites will continue to have high priority in future R & D programmes of the FRPRC. Problems of FRP product development for cryogenic applications, high temperature applications, involving thermal environments of 200°C and above, the design and development of an all-composite wing model for a combat aircraft like Rafale, and similar problems will prove challenging and are therefore worth undertaking. It is only when one is confronted with the various challenging problems of designing and developing hardware which has to meet the specifications stipulated by a client or user that all the theoretical/analytical studies are put to practical use and become meaningful. Otherwise, it is something like 'love's labours lost'!

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